DOCUMENT RESUME

ED 144 588 IR 005 206

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TITLE The Wooly Mammoth as a Computer-Simulated Scientific Problem-Solving Tool.
NOTE 13p.

EDRS PRICE MF-$0.83 HC-$1.67 Plus Postage.
DESCRIPTORS *College Science; *Computer Assisted Instruction; *Problem Solving; *Programing Languages; Science Education; Science Teachers; Scientific Attitudes; *Scientific Methodology

ABSTRACT

Mammo I and Mammo II are two versions of a computer simulation based upon scientific problems surrounding the finds of carcasses of the Wooly Mammoth in Siberia. The simulation program consists of two parts: the data base and program logic. The purpose of the data pieces is to provide data of an informative nature and to enable problem solvers to test, formulate, and reformulate hypotheses. The program logic accepts natural language data requests, analyzes the requests and checks the results for a match with existing data, displays the data to the problem solver, stores information about the problem solver, and checks consistency between data chains and conclusion. In addition, Mammo II provides content-free problem-solving heuristics to guide, shape, or direct the process used by the student. Mammo has been used to train prospective science teachers and to study selected parameters of human problem-solving. (WBC)

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The Wooly Mammoth as a Computer-Simulated Scientific Problem-Solving Tool

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Overview

Several general models of problem solving have been proposed which originate from various theoretical orientations (Dewey, 1910; Johnson, 1955; Polya, 1945; Wallas, 1926). These models share many comonalities in that they consider similar steps, although interpretations of each step may vary. Using Dewey's (1910) model as an examplar it can be noted that problem solving is a multi-staged affair described as follows:

Stage 1: The recognition of a problem, or a "felt difficulty;"

Stage 2: The location and definition of the problem or the isolation of revelant features;

Stage 3: The formulation of possible, alternative solutions;

Stage 4: Mulling over or reasoning through the various possibilities to determine the most likely one; and

Stage 5: Testing the selected solutions.

Although scientists and psychologists have long inquired about the nature of how man solves problems, most of the studies have focused upon the solution to problem with single correct answers. It can be argued however, that the study of how problems are solved can yield much insight into how man thinks. Given the assumption that problem solvers employ a wide range of skills and strategies, complex problems are needed to elicit those behaviors in order to detect and study them.

We might define a complex problem as one having two characteristics. First, a rational (i.e., scientific) approach may be employed in the search for a solution. Second, the problem is rich in data which implies that various possible conclusions can be supported, to some degree, by these data.

Wooly Mammoths

"The Arctic Ocean is bordered across most of Eurasia and North America by low, mostly flat plains that dip gently into the sea, called the tundra. With an average annual temperature of two degrees above zero the tundra remains to the south, the water runs into the river and begins a migration to the Artic Ocean, but the mouths of these great rivers are still frozen solid in these cold, northerly reaches and present an impenetrable dam to the advancing waters. The water spreads out over the low landscape forming innumerable lakes, ponds and swamps. The water has no choice but to sit and wait for the thawing of the river mouth - it can't evaporate into the cold air, and it can't sink into the ground because it's permanently frozen to depths of hundreds of feet.

About one seventh of the entire land surface of the earth is permanently frozen and the greater part of that is covered with a layer, varying in thickness from a few feet to more than a thousand feet, of studd we call muck. Only the top two or three feet of the muck ever thaws in the short artic summer only to freeze solid again during the winter. Ten feet down the passage of the seasons goes by completely unnoticed.

When the mouths of the great rivers finally open, much of the water drains away into the Ocean, carrying some of the muck with it. Then, occasionally, the excavated muck leaves to reveal one of nature's great oddities, the frozen remains of the great wooly mammoth.

The most famous of these, the Beresovka mammoth was discovered by a Siberian tribesman around the turn of the century. It was sticking headfirst out of a bank of the Beresovka River, a tributary of the large Kolyma which empties into the Arctic Ocean. A scientific expedition was sent by the National Academy of Science from St. Petersburg in accordance with an edict

from the Czar. The members of this company built a shack over the corpse and lighted fires within to thaw it out. They then dismembered it carefully, packed up the parts, refroze them in the air outside, and sledded them to the Trans-Siberian Railroad.

Much of the head, which was sticking out of the bank, had been eaten down by wolves and other local animals, but most of the rest was perfect. Most important, however, was that the lips, the lining of the mouth and the tongue were preserved. Upon the tongue as well as between the teeth, were portions of the animal's last meal, which for some reason he had not had time to swallow.

This meal proved to have been composed of delicate sedges and grasses and - most remarkably - of fresh buttercups in flower. The stomach contained many more quarts of the same material, undigested and not decomposed. The exterior of the mammoth was whole and perfect with none of its two foot hair rubbed or torn off. The meat was fresh, although it started to rot when thawed, and the sled dogs ate it with enthusiasm relieving the party from carrying additional supplies for the dogs. Unlike most mammoth finds the Beresovka mammoth had a broken hip, but like others it was healthy and robust, upright and with no apparent cause of death.

Mammoth remains are found widely distributed over Siberia and in Alaska. Their bones are spread over the floor of the Artctic Ocean where ships have dragged them up. And, 200 miles to the north, in the New Siberian Islands, mammoth remains are thickest of all.

How does one go about killing healthy, robust, 5 ton animals leaving no apparent cause of death and then manage to preserve them in the condition described using only natural means? What processes of nature could combine to concoct such a wild story?" The above scenario introduces you to a unique

and rare experience in an undergraduate curriculum: the opportunity to attempt to solve a real and complex problem in science. The experience which is simulated by a computer, is also a vehicle to study human problem solving of a scientific nature.

The Wooly Mammoth problem was selected because of it is:

1. a real problem confronting science,
2. rich in available data from scientific expeditions,
3. complex in that the scientific method seems likely to be productive in conceptualization,
4. not overly dependent upon extensive scientific or mathematical sophistication in the problem solver, and
5. is extremely enaging due to the seemingly contradictory findings regarding the cadaver.

Because of these characteristics, Wooly Mammoth is well suited to study scientific problem solving and decision making as expressed in these basic questions.

How does one solve complex problems ?

Can a person become a better problem solver?

What discrimates the better problem solver?

What environments facilitate problem solving?

To what extent can the study of problem solving be automated?

Mammo

Mammo is a computer simulation of the Wooly Mammoth problem which serves as a problem-solving environment designed to confront individual or small groups of problem solvers with a complex task. The simulation program consists of two parts: the data base and program logic.

Over 200 pieces of data, ranging from 200 to 800 words in length were abstracted from technical and popular writings on the topic of the Woolly Mammoths and associated topics (See Appendix A for sample data).

The purpose of the data pieces is to provide data of an informative nature and to enable problem solvers to test, formulate, and re-formulate hypotheses. The program logic of Mammo:

1. accepts natural language data requests,
2. analyzes the requests and checks the results for a match with existing data,
3. displays the data to the problem solver,
4. stores information about the problem solver,
5. checks consistency between data chains and conclusions, and
6. in some cases, provides content-free hints and cues of an heuristic nature.

The environment provided is a 32 terminal IBM 1500 series using Coursewriter II with CRT, image, and audio terminals. It is interactive and operates in a natural language free response format.

Drs. Riban and Szabo (1968) conceived of the Mammo concept during graduate school experiences at Purdue. Although Mammo was designed to run on a computer it was piloted in non-computer mode with high school students and university undergraduates. It was programmed into the IBM 1500 in 1973 by Thomas Rhoades and Anthony Lazzaro under the direction of Dr. Szabo (Szabo and Rhoades, 1977).

Student Progress-Mammo I

A simulation is worth 1000 K of words; nevertheless, an attempt will be made in writing to describe Mammo from the user's point of view. After signing on, the user, usually a student, is instructed in the use of the terminal, if necessary. He then receives a written copy of the confrontation similar to the first 8 paragraphs of the second section of this paper. The confrontation provides some background information and hopefully, rouses the curiosity necessary to motivate the student to decide to try to solve the problem.

The student is requested to write down all hypotheses he can generate that might lead to solution of the problem. Note that the program, like real life, never explicitly states the problem to be solved. The computer then suggests that the student query the computer i.e., request data that could be used to test the hypotheses generated. At this point, the computer is indirectly structuring a scientific approach to the solution (hypothesize, gather data, etc.).

For consistency with reality (fidelity) the student never sees a listing of available data which might structure of influence his solution search. Instead, he types in a natural language request (up to 3 line of text) which is matched with stored data titles using an edit and keyword routine.

For example, a student might request, "What was the age of the mammoths?" This simple statement is deceptive. Does the student wish to know the number of years since mammoths became extinct? the actual age of the Beresovka Mammoth at death? the actual age (average) of mammoths at time of death in general? This example points out: 1) difficulties of using a computer to assign semantic meaning to a string of characters and; 2) the tendency of problem solvers to formulate imprecise data requests. A successful data match results in the display of verbal data on the image screen. An unsuccessful match triggers the data request sequence again, but in a slightly different form. The student is given the three options of making a final conclusion and ending the program, reviewing hypotheses, or making another data request.

The data request used as an example will trigger display of a brief passage regarding the geologic age of the mammoths, abstracted from the scientific Journal Science. There are more than 200 separate pieces of data stored on randomly accessible images.

After the data are displayed, the student is given the option of requesting further data, making a final conclusion, or ending the program. Choosing the first operation results in an iteractive cycle beginning with another data request.

Mammo II

This describes one version (Mode I) of Mammo, called the Problem-Mode. Mammo I was designed to be free from hints or cues, both content-oriented and content-free, that might aid the student in solving the problem. A second mode (Mammo II) has been constructed to provide content-free problem-solving heuristics to guide, shape, or direct the process used by the student.

Operationally, Mammo II is identical to Mammo I except for two added features. The first, is quite simple: it attempts to force the student to evaluate his progress (hopefully, to test hypotheses with the data acquired) by requiring that the student type a brief conclusion after he has received data. The rationale is that a decision regarding the tenability of the hypothesis can and should be made continually as new data are received.

The second feature unique to Mammo II is the presentation of selected hueristics to "guide" the problem-solving approach or conclusions posed by the student, Mammo II heuristics simulate a real problem-solving environment.

As an example of this second unique feature of Mammo II, the conclusions made by students are compared with prestored conclusions which have been posed by scientists who studied the riddle of the mammoths. Further, logic "chains" or sets of data which are necessary and sufficient conditions to support these conclusions have been identified.

Presume that a student concludes that the mammoths froze to death but the student has neither requested nor seen the necessary data "chains" to support this conclusion. The computer heuristic which is likely to be displayed to the student, depending on specific terminology used is:

> "A comparison of all possible facts and data in memory areas implies you have seen insufficient data to form this conclusion".

On the other hand, suppose the student has requested the necessary data and concludes the mammoth froze to death. In this case, the heuristic is:

> "Hold on. Let's go back and check out your conclusion about the mammoth's death. Ask yourself questions like- if the mammoth really died in this way, what condition would the cadavers be in? Always check your conclusions. Consider the idea and determine what data you need to check your idea out, then request such data".

As another example, if the student triggers three pieces of data which have been determined to be logically related to the conclusion presented (by an outside authority), he receives the following heuristic message:

> "Good. Your last few requests for data show that you're following up a single line of thought. This is the only profitable way to attack a complex problem like this".

If on the other hand, the data request (and matches) indicate logically unrelated data being utilized as a basis for conclusions, the heuristic may be of the following form:

> "Do you have some strategy or plan of attack on the problem? What are you really trying to clarify?"

Discussion

In addition to specific experimental findings from studies recently completed and reported in the rest of this section, the following observations

represent a sample of those made by various individuals associated with the project.

First, attempting to solve the Wooly Mammoth using Mammo is psychologically engaging and elicits some strong positive reactions. Most students have to be reminded that it is time to quit and a large majority wish to know "the answer". The enjoyment of the experience is a function of the background (science or non-science) of the students and whether the problem is investigated in a group or as an individual effort.

Second, requests for data are more likely to be requests for conclusions. Students commonly ask questions like - "Did the mammoth drown"? rather than requesting data on analysis of the stomach contents of the cadaver (that is, data which could support or refute the hypothesis of death by drowning). The phenomenon of imprecise or unfounded data requests has been noted in many problem-solving studies and was a serious deterrent to the acquisition of sizable amounts of data in early Mammo programs. This problem has been corrected by the addition of a short segment which instructs the student to conceptualize the computer more like an encyclopedia than a genie with all the answers.

A third observation is that terminology used in requests for data varies considerably, with profound implications for keyword identification of the data requests and successful matches with stored data. Use of common synonyms from the Lorge-Thorndike dictionary of most commonly used words was quickly found to be unworkable as college students just don't use those terms in Mammo context. An examination of actual terminology used had led to substantial revisions which in turn permit much greater access to data.

A related problem is serendipity. Occasionally a student request triggers the display of data apparently not intended. Early in the development, a data request which included the words "weather" and "mammoth" would trigger data on the eating habits of mammoths. Although the student apparently desired climatological data, he actually obtained data on eating habits of the mammoth. The problem was soon discovered: the word -eat- is embedded in the word weather. Although this problem of incorrect matching of requests with displayed data results from limitation on CAI language restrictions and programming skills, it nonetheless simulates reality to some degree. The researcher always encounters data which: 1) he wasn't looking for and 2) may or not be relevant to the hypotheses presently under investigation. The effect of unwanted but potentially useful information upon a student's problem-solving strategy might be of considerable interest and value.

Summary

This paper describes a system of complex and scientific problem solving in its most recent (but hopefully not final) stage of evolutionary development A real world problem has been developed into a computer simulation program with two major modes. One presents the problem and assumes the student proceeds toward a solution in a more-or-less logical (i.e., non-random) fashion. The second mode attempts to guide the student into using certain strategies theoretically related to scientific problem-solving.

The complex answer processing routine which borders on an artifical intelligence application simulates numerous aspects of real problem solving including the fact that the student never knows the complete domain of available data.

Mammo has been used to train prospective science teachers and to study selected parameters of human problem-solving. It also serves as a

vehicle to test the limits of technological devices in recognizing specific human thought patterns and responding intelligently to them.